NASA TM-86722

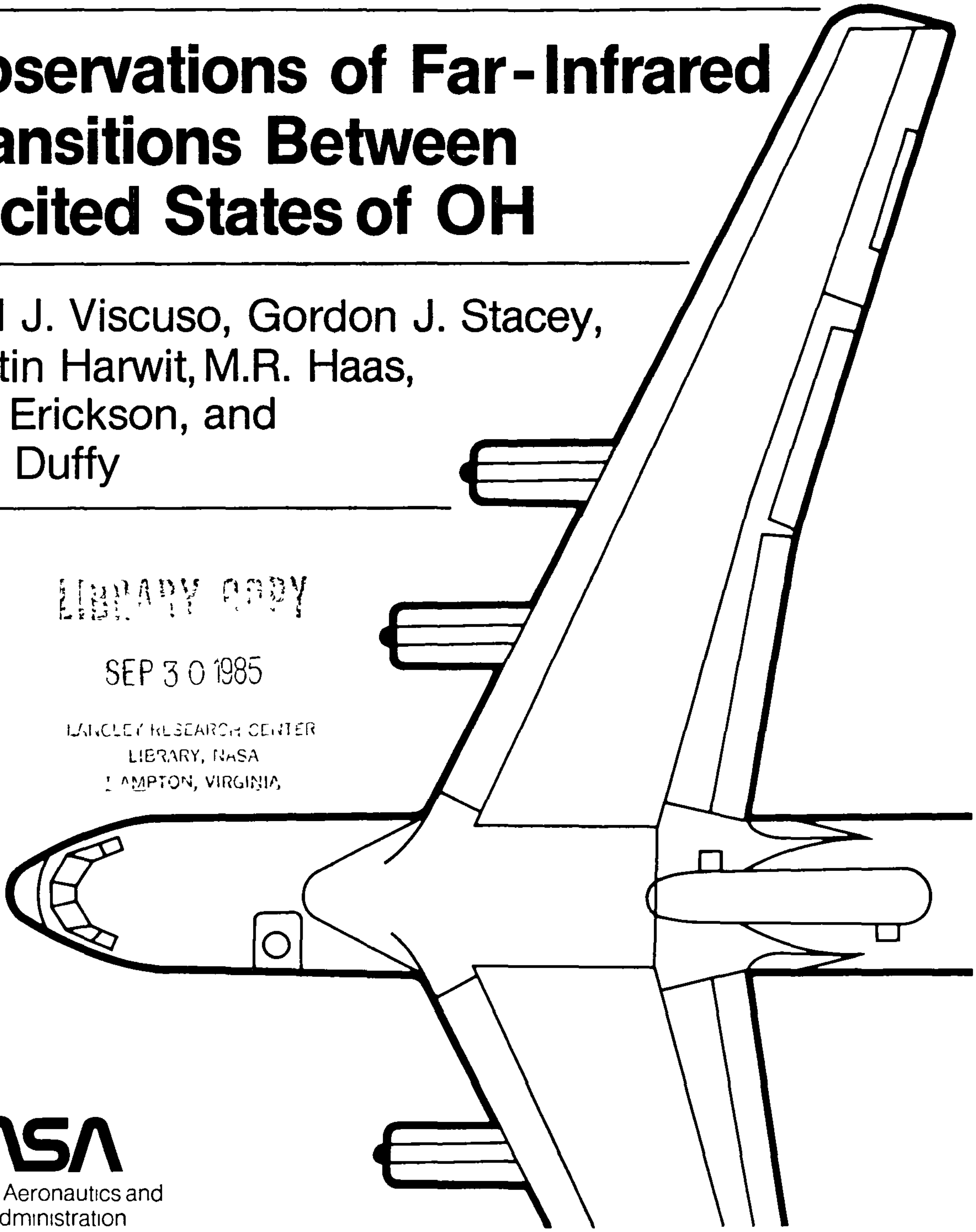
NASA Technical Memorandum 86722

Airborne Astronomy Program
Medium Altitude Missions Branch
Preprint Series 031

NASA-TM-86722 19850027520

Observations of Far-Infrared Transitions Between Excited States of OH

Paul J. Viscuso, Gordon J. Stacey,
Martin Harwit, M.R. Haas,
E.F. Erickson, and
P.B. Duffy



National Aeronautics and
Space Administration

NASA Technical Memorandum 86722

Airborne Astronomy Program
Medium Altitude Missions Branch
Preprint Series 031

Observations of Far-Infrared Transitions Between Excited States of OH

Paul J Viscuso
Gordon J. Stacey,
Martin Harwit, Cornell University, Ithaca, New York
M R. Haas, Mycol, Inc , Sunnyvale, California
E. F. Erickson,
P. B Duffy, Ames Research Center, Moffett Field, California

September 1985

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

N85-35833 #

ABSTRACT

In observations of the Kleinmann-Low Nebula of Orion we have detected 84.42 and 84.60 μm transitions between the $^2\Pi_{3/2}(J = 7/2)$ and $^2\Pi_{3/2}(J = 5/2)$ levels of OH with respective fluxes of $1.0 \pm 0.3 \times 10^{-17}$ and $1.4 \pm 0.4 \times 10^{-17}$ W cm^{-2}. When compared to 119 μm flux levels of OH (Watson 1982) and 163 μm flux levels of these radicals by Viscuso et al. (1985) (a companion paper in this issue), these results suggest appreciable self-absorption of OH line radiation within the Nebula. It is probable that the CO emission due to the $J = 31 \rightarrow 30$ rotational transition at 84.411 μm makes a substantial contribution to the observed 84.42 μm flux, and that it also is at least partially absorbed at the 84.42 μm OH transition frequency.

The 88.55 and 88.78 μm $^2\Pi_{1/2}$ ($J = 9/2$ to $7/2$) transitions of CH also were sought, but yielded only 1σ upper limits of $\leq 3 \times 10^{-18}$ W cm^{-2} each. A search of W3-IRS5 yielded upper limits to the 84.42 μm OH and 87.19 μm CO ($J = 30$ to 29) transitions of $\leq 2 \times 10^{-18}$ W cm^{-2}.

I. INTRODUCTION

Far-infrared studies of the Kleinmann-Low region of the Orion Nebula have shown that the OH gas cloud is heated sufficiently to emit both through the 119 μm $^2\Pi_{3/2}$ (J = 5/2 to 3/2) transitions (Storey et al. 1981, Watson 1982) and through the 163 μm $^2\Pi_{1/2}$ (J = 3/2 to 1/2) line (Viscuso et al. 1985). Figure 1 shows the energy level diagram for the pertinent transitions.

As discussed by Viscuso et al., the gas temperature must be sufficiently high to readily excite the $^2\Pi_{1/2}$ (J = 3/2) level which has an excitation temperature of 270 K. Watson has interpreted the 119 μm flux in terms of the column density of OH required in the Kleinmann-Low Nebula, and finds a column density of 1.5×10^{16} cm^{-2} and a resonant scattering depth of $\tau \sim 40$ for an assumed Doppler width corresponding to 30 km sec^{-1}. The high flux observed by Viscuso et al. in the 163 μm line then leads to the conclusion that the 119 μm line must also be quite strongly self-absorbed, a conclusion which points toward collisional de-excitation of the $^2\Pi_{3/2}$ (J = 5/2) state, to a molecular density of $n_{H_2} \sim 7\times10^6$ cm^{-3}, and a temperature $T_{gas} \sim 10^3$ K in the region where OH is emitting the observed flux. These results have prompted us to observe other OH transitions in order to examine the validity of this picture.

We also attempted to observe far-infrared CH and CO lines because of their importance in the interstellar gas-phase chemistry of carbon.

II. OBSERVATIONS

On the night of November 22-23, 1983, we observed Orion with the

NASA-Ames far-infrared cooled grating spectrometer (CGS) mounted on the Kuiper Airborne Observatory's 91-cm, bent-Cassegrain telescope. The CGS is described elsewhere (Erickson et al. 1984). The telescope was pointed at the Becklin-Neugebauer source with an accuracy of ~ 10", and we observed through a 4-mm circular aperture which defined a 1-arc minute field of view on the sky. The chopper was adjusted to provide a 4' throw of our beam. Direct observations of the 87 μm continuum gave a half-power width of roughly 1'.3. Spectra were taken at the continuum wavelength 87.08 μm; at 84.42 and 84.60 μm where the $^2\Pi_{3/2}$ (J = 7/2 to 5/2) transitions of OH were expected; and at 88.5 and 88.78 μm where the $^2\Pi_{3/2}$ (J = 9/2 to 7/2) transitions of CH occur. Later in the same flight we also observed W3-IRS5 at 87.08 μm, 84.42 μm and at the 87.19 μm CO (J = 30 to 29) transition.

The spectrometer had a six-element array of detectors separated by 0.0184 μm. The actual resolution of the instrument was 0.025 μm so that the spectra were slightly oversampled. Five of the six detectors were working reliably during the flight. At each wavelength setting the gratings were positioned so that most of the line radiation fell on the third detector in the array. The flux registered by that detector was then compared to the mean continuum flux registered by the other four.

Spectra were corrected for relative detector response by ratioing to spectra of the continuum around 87 μm. This spectral region is expected to be free of atmospheric and astronomical features. Absolute flux calibrations were obtained by multiplying ratioed spectra by an assumed continuum flux density of 1.2×10^5 Jy for a 50" beam (Erickson et

al. 1981). The resulting measurements of the lines are shown in Fig. 2. Table 1 summarizes our results. These measurements were obtained in integration times of one to two minutes per line. The predicted and observed wavelengths agree to within one part in 4000, which gives us added confidence in the detections reported here. The above errors include a $\pm 20\%$ contribution from the estimated uncertainty in flux calibration, and correspond to an in-flight system NEP of $\sim 1.6 \times 10^{-13}$ Watt $Hz^{1/2}$.

On W3-IRS5 we followed the same procedure of comparing spectral regions containing expected line radiation, with the 87.08 μm band, expected to be devoid of lines. No lines were detected. The relative detector response calibrated on M42 was used in establishing the upper limits for OH and CO recorded in Table 1.

III. DISCUSSION AND CONCLUSIONS

The observed OH emission at 84.42 and 84.60 μm corresponds to a photon flux of order 5000 photons cm^{-2} sec^{-1} in each of the lines. This is the same as the photon flux reported by Watson for the 119 μm transitions. If collisional excitation and radiative de-excitation were the only mechanisms at play in the Nebula, we would expect the lower transition to show an appreciably higher photon flux than the upper one. This is because the $^2\Pi_{3/2}$ (J = 5/2) level is populated by collisions and by radiative transitions down the $^2\Pi_{1/2}$ and the $^2\Pi_{3/2}$ ladders. That the 84 and 119 μm lines have comparable photon fluxes suggests that the 119 μm radiation is self- absorbed. The $^2\Pi_{3/2}$ (J = 5/2) level is less populated than the J = 3/2 ground state,

hence self-absorption and collisional de-excitation of the 84 μm radiation is less likely than for the 119 μm radiation -- though Viscuso et al. argue for some self-absorption at 84 μm as well.

The apparent similarity in line strengths at 84.42 and 84.60 μm may be due to a mechanism described by Viscuso et al., as follows: We expect a contribution at 84.41 μm from the (J = 31 to 30) transition of rotationally excited CO (Watson 1982), and our spectral resolution is inadequte to resolve this line from the shorter wavelength OH transition at 84.42 μm. However, the $^2\Pi_{3/2}$ (J = 7/2) negative-parity state is collisionally excited 1.5 times as frequently as the positive-parity state. In the absence of other effects the 84.6/84.4 μm line ratio might be expected to be ~ 1.5. Moreover, the Doppler broadening of these lines (Watson 1982) is expected to be comparable to their separation of ~32 km sec^{-1}. It appears to us, therefore, that a Bowen resonance fluorescence mechanism (Osterbrock 1974) might additionally be in operation here: if the CO and OH emission originates in the same region, then some of the CO emission at 84.41 μm could be absorbed by OH molecules in the $^2\Pi_{3/2}$ (J = 5/2) state because of the higher optical depth of the OH transition. The observer would merely be seeing a line strength characteristic of the gas temperature in the broadened, optically thick OH line.

Finally, we would like to acknowledge a private communication from Dr. Dan Watson after this paper was completed. He reports that the Berkeley group has also obtained comparable line strengths for the 84.42 and 84.60 μm transitions.

ACKNOWLEDGEMENTS

The Cornell group was supported through NASA grant NSG-2347. The NASA-Ames group was supported by the NASA UPN 352 program. Both groups wish to express their appreciation to the NASA-Ames KAO staff for making this flight so successful.

Table 1. Line Radiation Observed in M42 and Upper Limits for W3-IRS5

Source	Wavelength	Molecule	Transition	Line Flux and Uncertainty
M42	84.42 μm	OH	$^2\Pi_{3/2}$(J=7/2 to 5/2)	$10\pm3\times10^{-18}$ W cm^{-2}
	84.60	OH		14 ± 4
	88.55	CH	$^2\Pi_{3/2}$(J=9/2 to 7/2)	<3 ± 1.5
	88.78	CH		<3 ± 1.5
W3-IRS5	84.42	OH	$^2\Pi_{3/2}$(J=7/2 to 5/2)	<2 ± 1
	87.19	CO	(J=30 to 29)	<2 ± 1

REFERENCES

Brown, J. M., Schubert, J. E., Evenson, K. M. and Radford, H. E. 1982, Ap. J., 258, 899.

Erickson, E. F., Knacke, R. F., Tokunaga, A. T. and Haas, M. R. 1981, Ap. J., 245, 148.

Erickson, E. F., Haas, M. R., Augason, G. C., Hollenbach, D. J., Simpson, J. P., Houck, J. R., Harwit, M. O. and Rank, D. M. 1984, Infrared Physics, "Special Issue on CIRP 3."

Storey, J. W. V., Watson, D. M. and Townes, C. H. 1981, Ap. J. Letters, 244, L27.

Osterbrock, D. E. 1974, Astrophysics of Gaseous Nebulae, Freeman, San Francisco, p. 89.

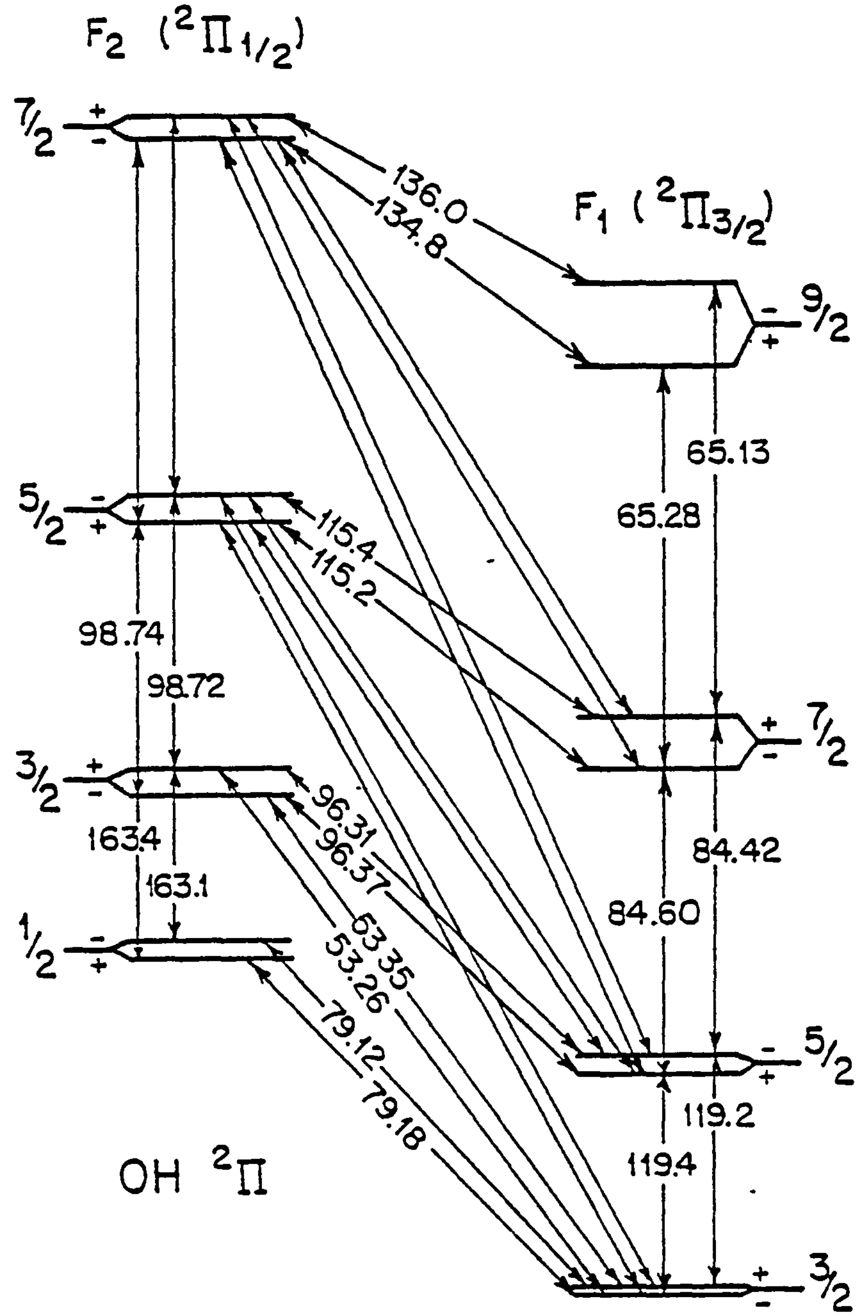
Watson, D. M. 1982, University of California, Berkeley, Physics Department Thesis: "Shock Waves and Mass Outflow in the Orion Molecular Cloud: Observations of Far-Infrared Emission Lines of Carbon Monoxide, Hydroxyl, and Ammonia."

Viscuso, P., Stacey, G., Fuller, C., Kurtz, N. and Harwit, M. 1985, Ap. J., this issue.

FIGURE CAPTIONS

Figure 1 - Level diagram for OH, after Brown *et al.* 1982.

Figure 2 - Plots of the observations at 84.42 and 84.60 μm. The sloping baseline is due to differences in the instrumental response at 84 and 87 μm.



F2 (2Π1/2)
F1 (2Π3/2)
7/2
5/2
3/2
1/2
9/2
7/2
5/2
3/2
136.0
134.8
115.4
115.2
96.31
96.37
53.35
53.26
79.12
79.18
98.74
98.72
163.4
163.1
65.13
65.28
84.42
84.60
119.2
119.4
OH 2Π

Fig. 1

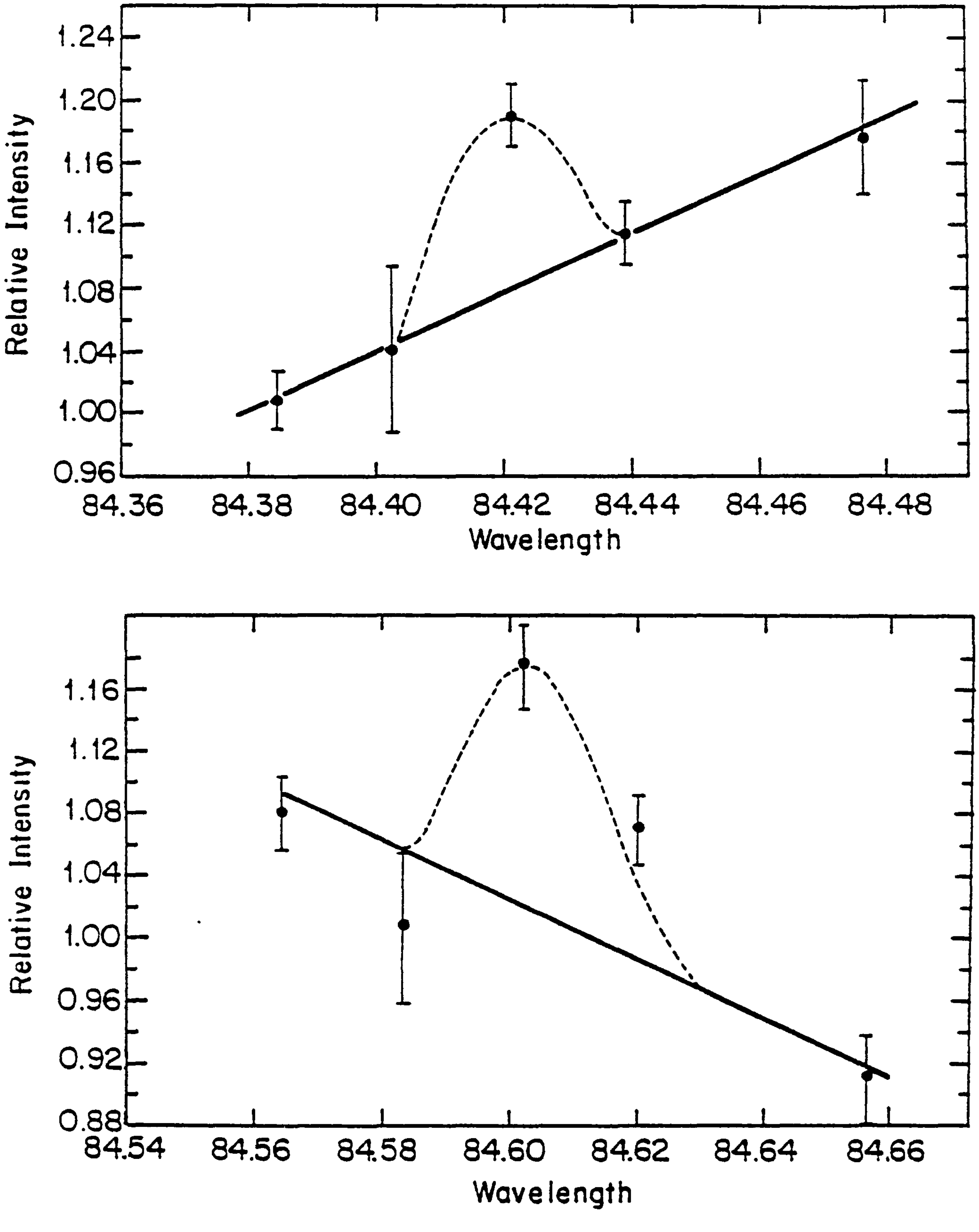

Relative Intensity
1.24
1.20
1.16
1.12
1.08
1.04
1.00
0.96
84.36
84.38
84.40
84.42
84.44
84.46
84.48
Wavelength
Relative Intensity
1.16
1.12
1.08
1.04
1.00
0.96
0.92
0.88
84.54
84.56
84.58
84.60
84.62
84.64
84.66
Wavelength

Fig 2

1 Report No NASA TM-86722	2 Government Accession No	3 Recipient's Catalog No
4 Title and Subtitle OBSERVATIONS OF FAR-INFRARED TRANSITIONS BETWEEN EXCITED STATES OF OH		5 Report Date September 1985 6 Performing Organization Code
7 Author(s) Paul J. Viscuso,* Gordon J. Stacey,* and Martin Harwit,* M. R Haas,† E. F. Erickson,‡ and P. B. Duffy†		8 Performing Organization Report No 85223
9 Performing Organization Name and Address *Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853 †Mycol, Inc., Sunnyvale, CA 94087 ‡Ames Research Center, Moffett Field, CA 94035		10 Work Unit No 11 Contract or Grant No
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		13 Type of Report and Period Covered Technical Memorandum 14 Sponsoring Agency Code 352-02-03
15 Supplementary Notes Preprint Series #31. Supported by NASA grants. Point of Contact. L. C. Haughney, Ames Research Center, M/S 211-12, Moffett Field, CA 94035 (415) 694-5339 or FTS 464-5339		

16 Abstract

In observations of the Kleinmann-Low Nebula of Orion we have detected 84.42 and 84.60 μm transitions between the $^2\Pi_{3/2}(J = 7/2)$ and $^2\Pi_{3/2}(J = 5/2)$ levels of OH with respective fluxes of $1.0 \pm 0.3 \times 10^{-17}$ and $1.4 \pm 0.4 \times 10^{-17}$ W cm^{-2}. When compared to 119 μm flux levels of OH (Watson 1982) and 163 μm flux levels of these radicals by Viscuso et al. (1985) (a companion paper in this issue), these results suggest appreciable self-absorption of OH line radiation within the Nebula. It is probable that the CO emission due to the $J = 31 \rightarrow 30$ rotational transition at 84.411 μm makes a substantial contribution to the observed 84.42 μm flux, and that it also is at least partially absorbed at the 84.42 μm OH transition frequency.

The 88.55 and 88.78 μm $^2\Pi_{1/2}(J = 9/2$ to $7/2)$ transitions of CH also were sought, but yielded only 1σ upper limits of $\leq 3 \times 10^{-18}$ W cm^{-2} each. A search of W3-IRS5 yielded upper limits to the 84 42 μm OH and 87 19 μm CO (J = 30 to 29) transitions of $\leq 2 \times 10^{-18}$ W cm^{-2}.

17 Key Words (Suggested by Author(s)) Far-infrared: OH spectra Nebulae. Orion K-L	18 Distribution Statement Unlimited Subject Category - 89

19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 13	22 Price* A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161

End of Document